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SINGLE MODE OPTICAL WAVEGUIDE FIBRE
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SUBSTITUTE SPECIFICATION

SINGLE MODE OPTICAL WAVEGUIDE FIBRE

FIELD OF THE INVENTION

This invention relates to a single mode optical waveguide fibre and preferably to an optical fibre of a type that exhibits low but non-zero dispersion at a wavelength λ typically in the order of 1550 nm. The optical fibre is, for convenience, referred to in this specification and more generally as a non-zero dispersion shifted fibre.

BACKGROUND OF THE INVENTION

A conventional single mode fibre (SMF) typically exhibits zero dispersion in the 1310 nm wavelength region, but high dispersion (in the order of -17 ps $nm^{-1}km^{-1}$) in the 1550 nm region. In this specification the convention that assumes SMF has negative dispersion at λ = 1550 nm is adopted.

Dispersion shifted fibre (DSF) has been developed to take advantage of the inherently low attenuating properties of optical fibre at 1550 nm and the availability of fibre amplifiers, but dispersion shifted fibre exhibits enhanced non-linear effects such as four-wave mixing (FWM) and self-phase modulation (SPM). Non-zero dispersion shifted fibre (NZDSF) has been developed to avoid the non-linear effects of the DSF fibre and for use in telecommunication systems that employ high power lasers, high bit rate transmissions and wavelength division multiplexing (WDM). Non-zero dispersion shifted fibre typically has a zero dispersion wavelength positioned slightly outside of the range 1530 nm to 1570 nm.

Prior art non-zero dispersion shifted fibres that have been sold commercially and described in the relevant literature have a central core region and at least one circularly symmetrical annular region positioned within the light guiding region of the fibres. The central core

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region has an average refractive index which is different from that of the surrounding annular region and, in the case of a fibre having two annular regions, the outer annular region has an average refractive index that is higher than that of the inner annular region. The average refractive index of the core region normally is greater than that of both of the annular regions.

SUMMARY OF THE INVENTION

The present invention has evolved from the development of a fibre geometry that permits a greater number of degrees of freedom to be exploited in the design of non-zero dispersion shifted optical waveguide fibre for use in various applications.

Broadly defined, the present invention provides a single mode optical waveguide fibre having a light guiding region that includes a central core region, a surrounding region that surrounds the central core region, and at least three angularly separated regions being disposed radially outwardly from the central core region. The central core region has an average refractive index n_0, the surrounding region having an average refractive index $n_1<n_0$, and each of the angularly separated regions has a non-circular cross-section and has an average refractive index $n_2>n_1$.

The outwardly disposed, angularly separated regions may be considered as "side core regions" and are hereinafter referred to as such.

The core and side core regions and may be composed of any transparent medium, such as silica or doped silica.

The invention as above defined differs from known non-zero dispersion shifted fibres, in that the side core regions are provided in lieu of the annular regions that surround the central core in the known fibres. Two or more of the side core regions may be positioned on a common notional circle.

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The characteristics of the fibre in accordance with the present invention may be varied from one fibre to another by varying any one or more of the following elements in the fibre:

(a) The average refractive index n_0 and the radial profile of the refractive index of the central core region of the fibre.

(b) The cross-sectional area of the central core region of the fibre.

(c) The average refractive index n_1 and the radial profile of the refractive index of the region surrounding the central core region of the fibre.

(d) The cross-sectional area of the region surrounding the central core region of the fibre.

(e) The average refractive index n_2 and the radial and circumferential profiles of the refractive index of the side core regions of the fibre.

(f) The cross-sectional area of each of the side core regions of the fibre.

(g) The configuration of each of the side core regions of the fibre.

(h) The number of the side core regions in the fibre.

(i) The spatial relationship of the side core regions in the fibre.

PREFERRED FEATURES OF THE INVENTION

The side core regions preferably have a generally arcuate or rectangular cross-sectional configuration.

The side core regions preferably are positioned equi-angularly around the central core region and preferably have a common cross-sectional configuration. However, the side core regions may be positioned and configured in an irregular manner, provided that the overall geometry does

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not give rise to unwanted artefacts, for example unwanted birefringence.

The optical fibre in accordance with the present invention most preferably has at least four equi-angularly positioned side core regions, and all of the side core regions preferably have a common cross-sectional size and configuration.

The optical waveguide fibre may have a doped silica core, that incorporates the central core region and the surrounding region, and a silica cladding. The side core regions may be located within the surrounding region. The side core regions preferably are located at least in part within the silica cladding.

The central core region and the side core regions may have average refractive indexes in that are enhanced relative to that of undoped silica and wherein the surrounding region may have an average refractive index that is depressed relative to that of undoped silica.

The invention will be more fully understood from the following description of preferred embodiments of single mode non-zero dispersion shifted optical fibres and a preferred method of forming a preform from which optical fibre may be drawn. The description is provided with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings -

Figure 1 shows a diagrammatic (idealised) representation of the cross-section of an optical fibre that incorporates side core regions.

Figures 2A and 2B show refractive index profiles that are applicable to the optical fibre shown in Figure 1 and

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as seen in the directions of section planes A-A and B-B in Figure 1.

Figure 3 shows a cross-sectional representation of an optical fibre that has been designed with side core regions to exhibit a very small dispersion slope over the wavelength region 1530 to 1570 nm.

Figures 4A and 4B show refractive index profiles that are applicable to the optical fibre shown in Figure 3 and as seen in the directions of section planes A-A and B-B in Figure 3.

Figure 5 shows a cross-sectional representation of an optical fibre that has been designed with side core regions to exhibit a non-linear effective area approaching 100 μm^2.

Figures 6A to 6B show refractive index profiles that are applicable to the optical fibre shown in Figure 5 and as seen in the directions of section planes A-A and B-B in Figure 5.

DETAILED DESCRIPTION OF THE INVENTION

In making reference to the drawings, Figure 1 shows a diagrammatic representation of the cross-section of one form of an optical fibre that embodies the present invention. However, it will be understood that the various concentric regions that are shown in Figure 1 are not drawn to scale. The diameter of a cladding portion 10 of the fibre will typically have a diameter in the order of 30x that of a central core region 11 of the fibre.

The region of the fibre through which a major portion of transmitted light is guided (herein referred to as "the light guiding region") may be considered for convenience as being bounded by the inner margin 12 of the cladding 10 in the case of the fibre as illustrated in Figure 1. More specifically, the light guiding region includes the central core region 11 and four angularly spaced side core regions 13, each of which is disposed radially outwardly from the central core 11.

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The central core region 11 is located within a core-surrounding region 14 which extends outwardly to the inner margin 12 of the cladding and, as illustrated, the side core regions 13 are disposed within the core-surrounding region 14. However, it should be understood that the boundary 12 between the core surrounding region 14 and the cladding 10 may not be delineated clearly and that the side cores 13 may be disposed at least partially within the cladding 10 of the fibre, as in the fibre that is illustrated in Figure 5. With this in mind it will be understood that the light guiding region may extend into the cladding 10 and need not be bounded by the inner margin 12 of the cladding.

The relationship of the refractive indexes of the various regions of the optical fibre will be dependent upon the characteristics required of the fibre for any given application. However, as an example, the central core region 11 and the side core regions 13 may have average refractive indexes n_o and n_2 that are enhanced relative to that of undoped silica, and the core surrounding region 14 may have an average refractive index n_1 that is depressed relative to that of undoped silica. These index relationships are indicated in Figures 2A and 2B in respect of the fibre cross-section that is illustrated in Figure 1.

The fibre has four equi-angularly spaced side core regions 13, although it will be understood that the fibre may be fabricated with three or more side core regions. Again depending on the characteristics required of the fibre, the side core regions 13 will normally be disposed on a common circle, that is at equal radial distances from the axis of the fibre, and the side core regions 13 will normally have substantially the same cross-sectional configurations. As illustrated, each of the side core regions 13 has a generally arcuate cross-sectional configuration.

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The refractive index profiles of the above described fibre, as seen in the directions of section planes A-A and B-B, are shown in Figures 2A and 2B.

The fibre as illustrated in Figure 1 may be manufactured in various ways, one of which is described briefly as follows by way of example.

The fibre will be drawn from a preform that is fabricated using modified chemical vapour deposition of required material within an undoped silica tube. Portions of the preform corresponding to the side core regions 13 will be formed by depositing doped silica to a required thickness within the silica tube and by etching away portions of the deposited material to leave four equi-spaced longitudinally extending lands of the doped silica. Thereafter, further layers of differently doped silica will be deposited within the tube, including over the lands, to form the core-surrounding region 14 and the central core region 11 of the fibre to be drawn from the preform. Finally, the entire structure, including the deposited material, will be collapsed in the usual manner to form a solid preform from which the fibre may be drawn.

Figure 3 shows a diagrammatic representation of the cross-section of a second form of optical fibre that embodies the features of the present invention. This is similar to that shown in Figure 1 and like reference numerals are employed to indicate like elements.

Characteristic features of the fibre as illustrated in Figure 3 are summarised as follows:

Diameter of cladding 10 125 μm

Diameter of central core region 11 8.4 μm

Diameter (12) of core-surrounding region 14 20 μm

Dimension of each side region core 13 1.72 x 6.36 μm

Radial displacement of each side core region 8.0 μm

Refractive index peak of cladding 10 1.444

Refractive index peak of central core region 11 1.454

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Refractive index peak of side core regions 13 1.454 (uniform)
Refractive index peak of core-surrounding region 14 1.441

The refractive index profiles of the fibre of Figure 3 as seen in the directions of section planes A-A and B-B are shown in Figures 4A and 4B respectively.

The fibre as represented in Figures 3 and 4 exhibits a substantially constant dispersion across the EDFA band, and properties of the fibre at a wavelength of 1550 nm are summarised as follows:

Dispersion	+3.41 ps $nm^{-1}km^{-1}$
Dispersion slope	-0.004 ps $nm^{-2}km^{-1}$
Cutoff wavelength	1420 nm
Petermann II area	36.4 μm^2
Non-linear area	35.2 μm^2

The fibre as represented in Figures 3 and 4 exhibits a dispersion of +3.57 ps $nm^{-1}km^{-1}$ at λ = 1530 and +3.35 ps $nm^{-1}km^{-1}$ at λ = 1570.

Figure 5 shows a diagrammatic representation of the cross-section of a third form of optical fibre that embodies the features of the invention. Here again, this is somewhat similar to that shown in Figure 1 and like reference numerals are employed to identify like elements.

Characteristic features of the fibre as illustrated in Figure 5 are summarised as:

Diameter of cladding 10 125 μm
Diameter of core region 11 6.3 μm
Diameter (12) of core-surrounding region 14 10.6 μm
Dimension of each side core 13 3.39 x 3.84 μm
Radial displacement of each side core 14.0 μm
Refractive index of cladding 10 1.444
Refractive index peak of core region 11 1.455
Refractive index peak of side cores 13 1.459 (graded)
Refractive index peak of core-surrounding region 14 1.441

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The refractive index profiles of the fibre of Figure 5, as seen in the directions of section planes A-A and B-B, are shown in Figures 6A and 6B respectively.

The fibre as represented in Figures 5 and 6 has a nonlinear mode area of 85 μm^2, and the properties of the fibre at a wavelength of 1550 nm are summarised as follows:

Dispersion	-2.56 ps $nm^{-1}km^{-1}$
Dispersion slope	+0.083 ps $nm^{-2}km^{-1}$
Cutoff wavelength	1271 nm
Petermann II area	51.4 μm^2
Non-linear area	85.4 μm^2

It is to be observed that the fibre as represented in Figures 5 and 6 has a Petermann II area much smaller than the non-linear area. This facilitates low bend losses and permits the splicing of the fibre to a standard single mode fibre with low loss, typically less than 0.5dB.

The optical fibres as previously described in the specification and illustrated in the drawings are but a few of a vast number of fibres that may be produced, to meet various requirements, by varying one or more of the characteristic features of the invention as defined in the following claims